Synopsis

Lightweight aluminium-silicon alloy is an attractive material for making engine cylinders in automobiles. It imparts good power to weight ratio to the engine. High silicon containing aluminium alloys are used in current engine block castings where the bore surface is etched or honed to partially expose the silicon particles to provide the primary contact between the piston ring and certain regions of the piston and the cylinder. Piston reversal near the top dead centre however causes starvation of lubrication which leads to wear. To explore the wear behaviour of etched aluminium-silicon alloys under nominally dry conditions and extreme lubricated conditions, a host of mechanical and spectroscopic techniques are used here to characterize mechanical and chemical changes caused by wear. In the absence of complex chemical transformations on the wear surface in dry condition, allows a close examination of surface and subsurface microstructures. Given this understanding of the wear under dry condition, we explore the effect of boundary lubrication, where chemical transformations leading to surface modifications are involved.

In dry sliding tribology of aluminium-silicon alloy slid against a steel ball four stages of wear are identified; ultra-mild wear, mild wear, severe wear and post severe oxidative wear. In the ultra-mild wear regime silicon particles bears the load. Transition to mild wear occurs when the protruded silicon particles disappear (by sinking and fracture) under higher pressure and sliding. The sinking of silicon particles under normal loading is further investigated using a naoindenter. It is found that the resistance to sinking of such particles into the matrix increases with the unexposed surface area to the buried volume of the particles. In that sense, small particles are seen to provide the stiffest resistance to sinking. While in ultra-mild wear regime the basic energy dissipation mechanism is sinking/tilting, in mild wear regime the subsurface is either in an elastic or an incipiently plastic state. Subsurface plasticity in mild wear regime leads to a grain refinement, fracture of silicon and nucleation of cracks at silicon-matrix interfaces but does not promote large scale flow of the matrix. Transition to severe wear occurs when the contact pressure exceeds the plastic shakedown limit. Under this condition gross plasticity leads to a severe fragmentation of silicon particles and the fragmented silicon are transported by the matrix as it undergoes incremental straining with each cyclic contact at the asperity level. A large reduction in the inter-particle distance compared to that in a milder stage of wear, gives rise to high strain gradients in the severe wear regime which contribute to the enhancement of dislocation density. The resulting regions of very high strains at the boundaries of the recrystallised grains as well as within the subgrains lead to the formation of microvoids / cracks. This is accompanied by the formation of brittle oxides at these subsurface interfaces due to enhanced diffusion of oxygen. We believe that the abundance of such microcracks in the near surface region, primed by severe plastic deformation, is what distinguishes a severe wear regime from that in the mild wear. The transition from severe wear to post severe oxidative wear is thermally induced and it transfers the metal to metal contact interaction to metal to ceramic interaction. A thick oxide layer is abraded and spalls while the metal underneath continues to flow and delaminate.

A study of lubricated tribology of ultra-mild and mild wear regime of aluminium-silicon alloy shows that the initial stages of sliding friction is controlled by the abrasion of the steel pin by the protruding silicon particles of the aluminium-silicon disc. The generation of nascent steel chips helps to breakdown the additive in the oil by a cationic exchange that yields chemical products of benefits to the tribology. The friction is initially controlled by abrasion, but the chemical products gain increasing importance in controlling friction with sliding time. After long times, depending on the contact pressure, the chemical products determine sliding friction exclusively. In the mild wear chemically induced low friction is achieved in short periods of time whereas in ultra-mild wear regime it takes very long time to reach this low friction state. While the basic dissipation mechanisms are the same in the ultra-mild wear and mild wear regimes, the matrix remains practically unworn in the low pressure ultra-mild wear regime. In the higher pressure mild wear regime at long sliding times a small but finite wear rate prevails. Incipient plasticity in the subsurface controls the mechanism of wear.